EXPERIMENTAL OBSERVATIONS OF A STITCHED COMPOSITE WITH A NOTCH SUBJECTED TO COMBINED BENDING AND TENSION LOADING

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A series of tests was conducted to support development of an analytical model for predicting the failure strains of stitched warp-knit carbon/epoxy composite materials with through-thickness damage in the form of a crack-like notch. Measurements of strain near notch tips, crack opening displacement (COD), and applied load were monitored in all tests. The out-of-plane displacement at the center of the notch was also measured when the specimen was subjected to bending. Three types of loading were applied: pure bending, pure tension, and combined bending and tension.

Test Specimens. The composite specimens tested were fabricated from a carbon warp-knit fabric, containing fibers in the 0°, ±45°, and 90° directions. By areal weight, 44% of the fibers were configured in the 0° direction, 44% in the ±45° directions, and 12% in the 90° direction. After stitching, the preforms were infiltrated with 3501-6 epoxy using a resin-film-infusion process. Each specimen was 0.445 inches thick and 4.0 inches wide, with a 3.0-inch center crack-like notch. The center crack-like notch had a width of 0.02 inches for all tests except the pure bending (four-point bend) test, which used a notch width of 0.045 inches in the center to prevent the notch from fully closing in compression. The test specimens were 17.5 inches, 11.5 inches, and 14.0 inches in length, respectively, for the three loading types.

Test Apparatus. As shown in figure 1, loads were transmitted into the specimen through the pin/clevis connections at the top and bottom grips. The axial load controlled the tensile strains in the specimen, and using offset shims between the plane of the specimen and the loading line controlled the bending strains. The offset values used were approximately 0.22, 0.42, 0.61, 0.80 and 0.96 inches, with one specimen tested for each offset value.

Material non-uniformity including stitching location relative to gage location, twisting or uneven loading in the test fixture, and slight deviations of the location of the gages created measurable deviations in the recorded data. Thus, the strain measurements were viewed as a rough average of the strain field under the gages.

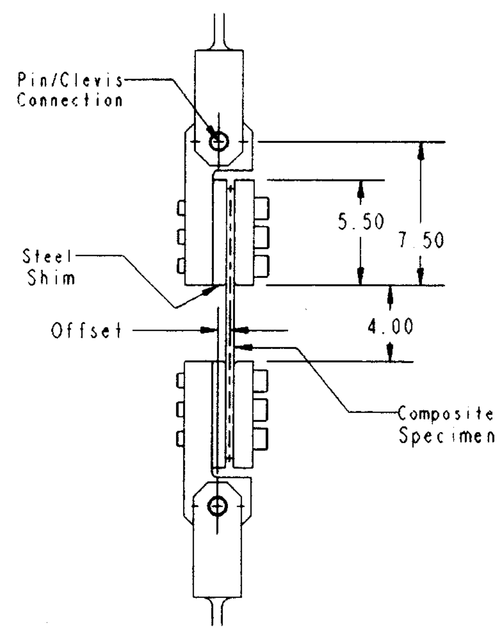

Figure 1. Combined bending and tension fixture diagram.

Experimental Results. Typical experimental data are presented in figures 2 and 3, for a pure tension test and a combined bending and tension test, respectively. By comparing the failure strains in these two figures, it is seen that the flexural (bending) strains were higher at failure than those for pure tension. Similar results for unnotched composite specimens have been reported in several previous studies, which show that a higher failure stress (strain) is measured in flexural specimens because much less material is under the maximum tension load. Note that in a tension test, the entire volume of the gage length is under the maximum tensile stress.

The results of the center notch four-point bend test indicated that the maximum tensile strain at the strain gage location was approximately 10,000 με and the compressive strain was approximately 11,000 με before failure. The specimen failed on the compressive side because the material has a lower compressive strength. The combined bending and tension specimens with the two largest offset values also failed on the compressive side. By comparing the tension only and bending only tests, it was shown that these specimens could experience a much higher strain in flexure than in pure tension.

The results of the combined bending and tension test indicated that the maximum tensile strain at the strain gage location, for those specimens that failed in tension, was approximately 10,000 με before failure. When no bending stresses were present in the pure tension test, however, the maximum tensile strain at the strain gage location only reached about 6000 με before failure. These results indicate that the presence of bending in the specimens significantly increased the amount of strain experienced before failure.

Discussion. The values of failing strain indicate that the more a specimen bends, the larger the amount of strain the outer surface can experience before failure. A larger failing stress (strain) has been shown to exist in composite specimens while under flexure compared to pure tension testing. Apparently, the presence of a notch, which greatly reduces the volume of material that experiences the maximum stress in a tension test, does not diminish the effect of flexure strength being greater than tensile strength. Thus one cannot assume a composite will fail whenever a volume of material, regardless of size, experiences a maximum stress or strain value as determined from tension testing. Fortunately, if this assumption is made, the error will be on the conservative side.

Any attempt at developing an analytical model for failure when combined bending and tension loads are present must take into account the volume of material experiencing the maximum stress, even when a stress riser such as a notch is present. Care must also be taken to account for compressive stresses, which can cause failure of the specimen as they did for the two largest offset values.

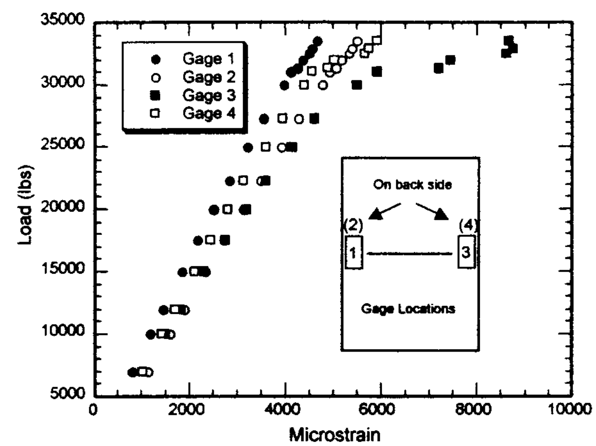

Figure 2. Load versus strain for pure tension test.

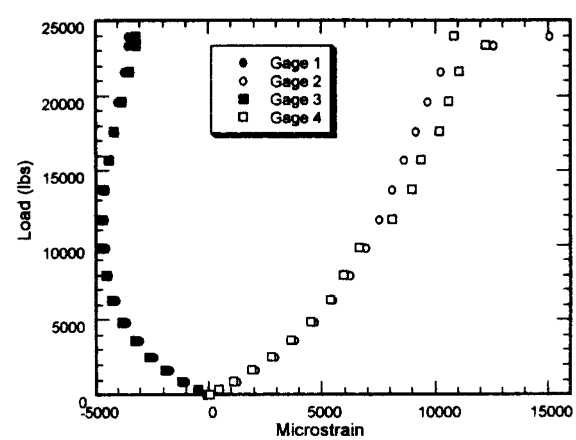

Figure 3. Load versus strain for 0.61 inch offset in combined bending and tension load test.